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WEIGHT LOSS AFTER AM AND PM SDV DIVES AND USE OF DDAVP

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NOTICES

TECHNICAL REVIEW AND APPROVAL

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The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

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Post-dive weight loss, as an estimate of body fluid loss, was obtained in 13 SEALs after 28 daytime (AM) and 66 nighttime (PM) man-dives in a SEAL Delivery Vehicle (SDV). Water temperature was 26 °C. AM weight loss averaged 1.25±0.14 kg for the 166±8 min dives; there was no significant correlation between weight loss and dive time. Nine divers received desamino-8-D-argnine (DDAVP, 20 μg intranasally) before one of their AM dives to determine if the drug lessened fluid loss. There was no difference in weight loss between DDAVP and no drug (PL) dives.

PM weight loss was 1.35±0.12 kg for the dives lasting 234±7 min. The weight loss was comparable to the AM dives, and represented 1.7% of total body weight. A significant correlation occurred for PM weight loss versus dive time, both for PL and DDAVP dives. The slope for all PM

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dives was 0.007 kg/min. Nine of 12 divers receiving DDAVP had less of a weight loss compared to their corresponding PL dives (0.95±0.19 kg and 1.51±0.14 kg respectively, $p<0.02$).

The weight loss data from the present study (AM & PM) were combined with previous PM data to predict weight loss versus dive time. The relationship for 130 dives lasting 85-385 min was:

$$\text{WEIGHT LOSS} = 0.004(\text{TIME}) + 0.472$$

Post-dive exercise heart rate was significantly elevated compared to pre-dive values only in PM dives, by 8±2 beats/min. Post-dive tympanic membrane temperature was 0.9±0.2 °C lower than pre-dive, but this was due to water cooling the ear canal tissues rather than an indication of hypothermia. Three-day diet surveys indicated adequate nutrient intake, but there was wide variability among subjects.

The present findings indicate that weight loss during SDV dives in temperate water will result in an average fluid loss on the order of 1.3 liters (1.4 qts) or 1.7% of body weight. DDAVP tended to lessen the fluid loss, but the magnitude of the effect was less than reported for laboratory studies. Further studies are warranted to determine whether DDAVP will appreciably enhance mission effectiveness in an operational setting.

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INTRODUCTION

A previous study (3) conducted in 1991 found an average weight loss of 1.31 kg after night dives in a SEAL Delivery Vehicle (SDV) in 26 °C water. The magnitude of the loss of body fluid was comparable to laboratory daytime immersions, rather than values obtained during nighttime laboratory studies. It was hypothesized that the larger than expected weight loss after night dives was due to shifts in circadian rhythm resulting from the conduct of continuous nighttime operations.

The opportunity arose to conduct another open-water study, at the same water temperature encountered previously, where it would be possible to obtain data from divers during daytime (AM) and nighttime (PM) SDV operations.

The first hypothesis to be tested was that fluid loss during AM dives would be similar to those measured during PM dives. Both the AM and PM dives were to be conducted as continuous operations; therefore, all divers would have presumably adapted their circadian rhythms to either day or night cycles for the AM and PM evolutions, respectively. Determining the magnitude of fluid loss versus dive time is an important variable for operational planners. The previous study had found no change in the magnitude of fluid loss for dives lasting 2-5 hours. Additional data obtained from the present study would refine the prediction of how much fluid would be lost.

The second hypothesis was that administering desamino-8-D-arginine vasopressin (DDAVP), an analog of naturally occurring antidiuretic hormone, would minimize loss of body fluid during long dives, irrespective of time of day. Intranasal administration of 20 μg of DDAVP has been shown to maintain plasma concentrations

of the drug and suppressed urine flow in hydrated subjects for 6 hours (13). Previous work has also shown that DDAVP will inhibit immersion diuresis by 80-90% during resting immersions in thermoneutral water (Lockette, personal communication). On the other hand, we found urine output to be comparable between DDAVP and no drug during 3 hours of intermittent swimming in 34 °C water (unpublished observations); urine output in both cases was low (0-391 ml/3 h). We did show, however, that the drug produced no untoward side effects, even in the presence of drinking 1 liter per hour of water in the post-dive period. It remained to be determined whether DDAVP would be an effective method to reduce fluid loss during open water dives.

METHODS

Subjects

Twelve U.S. Navy SEALs and one foreign exchange diving officer volunteered to participate in the study after signing informed consent. The protocol was approved by the NMRI Committee for Protection of Human Subjects and authorized by the Commanding Officer of SDV Team Two. The divers were undergoing advanced operator training for the SDV from January-April 1992. Measurements made in this study were obtained during February-March; subjects were therefore considered acclimated to warm weather conditions. Divers performed their normal daily activities during the period of the study and were not restricted with respect to diet, physical training, or the scheduling of dives.

The physical characteristics of the subjects are presented in Table 1. Mean skinfold thickness was obtained from the average of 7 sites: triceps, subscapula, anterolateral chest, axilla, abdomen, suprailiac, and anterior thigh. Percent body fat was calculated from the 7 sites according the method of Jackson and Pollack (4).

Dive Conditions

Data were collected before and after 30 AM and 70 PM man-dives (15 and 30 SDV operations, respectively). AM dives occurred from 0600-1600 hours, and PM dives from 1900-0500 hours. Ten of the PM man-dives involved mission specialists, the remaining 90 man-dives (AM and PM) were done in the capacity as the pilot and navigator of the SDV.

Divers wore either a lycra suit and cotton coveralls or a 1/8" neoprene wet suit and coveralls. A closed-circuit underwater breathing apparatus (MK-15) and full face mask were used. Surface water temperature was 26 °C (78.8 °F) and air temperature was 25-30 °C (77-86 °F). Average depth of the dive was 20 fsw (6.1 m), maximum depth was 40 fsw (12.2 m). For purposes of this study, dive time (to the nearest 5 min) was measured from the time subjects entered the water until they exited the water.

Body Weight Loss

Loss of body fluid was estimated by the difference between pre-dive and post-dive body weight, measured to the nearest 0.11 kg (0.25 lb), using a balance beam scale. Weight loss data were collected on 28 AM and 66 PM man-dives lasting 85-385 minutes. Pre-dive weights were obtained within one hour before the start of a dive; no

food or fluid was consumed between this weighing and the start of the dive. Post-dive weights were obtained within 30 minutes of completing a dive, before subjects had consumed any food or fluid. No food or fluid was consumed during the dive.

On some dives (see Annex A) subjects received either DDAVP (20 μg) or placebo (PL, saline) intranasally approximately one hour before the start of a dive. There were 9 and 19 DDAVP trials for AM and PM dives, respectively, and 19 and 47 PL trials for AM and PM, respectively. Subjects were blinded with respect to receiving DDAVP or PL; attempts were made to counterbalance DDAVP vs PL to minimize ordering effects.

Weight loss data were also normalized to the fractional weight loss for each subject to minimize differences in body weight. Fractional weight loss was computed as:

$$\text{FRACTIONAL LOSS} = (\text{PRE} - \text{POST}) / \text{PRE}$$

where PRE and POST are body weights measured in kg.

Unpaired t-tests were performed on post-dive loss of body weight to determine differences between AM and PM data. A one-way analysis of variance was done to determine differences in post-dive loss of body weight or fractional loss as a function of DDAVP vs PL for AM and PM dives. Least-squares regression of loss of body weight and fractional loss versus dive time were performed on data sets to analyze the temporal correlation with loss of body fluid. F-tests were conducted on the slopes of

each regression to ascertain differences between AM and PM and between DDAVP and PL.

Tympanic Membrane Temperature

Tympanic membrane temperature was recorded shortly before and after 94 man-dives (30 AM and 64 PM) using an infrared scanning otoscope (OTOTEMP 3000, Exergen, Newton, MA). Post-dive recordings were obtained after subjects swabbed their ear canal with tissue to remove any water. Differences between pre- and post-dive were tested statistically by paired Student's t-test.

Exercise Heart Rate

Exercise heart rate was measured in 52 trials (20 AM and 32 PM) before and after the dive. A five-minute step test was used to provide the exercise challenge (step height = 42 cm, stepping rate = 30/min, alternating legs on the step up). Pulse rate was manually counted for the first 15 seconds after stopping exercise. The difference in exercise heart rate between post-dive and pre-dive was analyzed by a one-tailed t-test. Standard regression techniques were used to assess correlations between dive time and the magnitude of change in post-dive heart rate.

Diet Survey

Three-day diet surveys were obtained in 10 subjects during the period 18-20 February, at the transition from PM to AM dives (AM diet). Surveys were obtained in all 13 subjects during 10-12 March, after the second series of PM dives had begun (PM diet). Each subject was provided a notebook and instructions to record all foods and beverages consumed during each 3-day period. Subjects were encouraged to

record the composition of mixed foods, amounts consumed, and the brand names of any items ingested. Diets were analyzed by computer (Auto-Nutritionist III, N-Squared Computing, Silverton, OR). Each subject's diet composition was averaged over each 3-day period. Two subjects had incomplete records for the AM period, and records were lost in 4 PM surveys; thus $n = 8$ for AM diets and $n = 9$ for PM diets. Group means for selected nutrients were obtained from the 3-day averages and expressed as per kg body weight.

Data Presentation

All data are expressed as the mean ±SEM. Statistically significant differences were accepted at the $p < 0.05$ level.

RESULTS

Dive Time, All Dives

Annex A lists dive times and changes in body weight for each diver in the sequence in which data were collected. Dive time for the 28 AM dives (166±8 min) was significantly shorter than for the 66 PM dives (234±7 min, $p<0.01$).

The average time for all AM and PM dives was 214±7 min; the distribution of dive times is shown in Figure 1 (top). Of all AM dives, 78.6% lasted 2-4 hours and only 2 exceeded 4 hours. In contrast, 55.6% of PM dives were 2-4 hours long, with 33 (48.5%) longer than 4 hours. Dive times were similar for DDAVP and PL trials in the respective AM and PM series.

Body Weight Loss, AM Dives

Post-dive weight loss for all AM dives averaged 1.25±0.14 kg; the distribution of weight loss is presented in Figure 1 (lower). Of all AM dives, 64.2% resulted in weight losses of 0.5-2.0 kg. No significant difference was detected between DDAVP (1.37±0.27 kg) and PL (1.19±0.16 kg) trials. Only one DDAVP trial resulted in a weight loss <0.5 kg.

Five of the 8 subjects who were tested both with PL and DDAVP had a 20-67% smaller weight loss with the drug compared to their PL trial. The average weight loss for these 8 comparisons was 1.67±0.22 and 1.43±0.32 kg for PL and DDAVP, respectively ($p>0.20$).

A modest correlation between dive time and weight loss was noted for PL in the AM series (slope = 0.008±0.003 kg loss/min dive time, $F= 5.959$, $p<0.05$), but not for DDAVP ($F = 0.325$). The combined data (DDAVP + PL) for AM dives is presented in Figure 2 (top); overall, there was no significant correlation of weight loss vs dive time (slope = 0.005±0.003 kg loss/min dive time, $F = 2.789$, $p>0.10$).

Fractional weight loss for AM dives is shown in Figure 2 (lower). No differences were detected between PL and DDAVP; the combined data yielded an average loss of 1.6±0.2% of total body weight. Likewise, for the combined data there was no significant correlation between fractional loss and dive time. The average rate of fluid loss (from the correlation slope) was 0.38±0.25% of total body weight per hour of dive.

Body Weight Loss, PM Dives

Figure 1 shows the distributions of dive time and weight loss for all PM dives. The average weight loss for all PM dives was 1.35±0.12 kg. For all PM dives, 63.7% resulted in weight losses of 0.5-2.0 kg; this was not statistically different from the AM results. Weight loss was significantly less during PM dives for DDAVP trials (0.95±0.19 kg) than for PL (1.51±0.14 kg, $p<0.02$).

Twelve subjects performed at least one DDAVP trial during night dives. Their first PL and DDAVP trials during PM dives revealed that 9 of 12 subjects had a 34-100% smaller weight loss with DDAVP compared to their PL trial. A significantly lower weight loss was observed in these 12 comparisons for DDAVP than for PL (0.72±0.16 vs 1.28±0.23 kg, respectively; $p<0.05$).

Figure 3 (top) illustrates weight loss versus dive time for PM dives. Significant correlations were noted for both PL (slope = 0.006 kg loss/min, F = 7.180, $p<0.025$) and DDAVP (slope = 0.008 kg loss/min, F = 8.244, $p<0.01$). There was no significant difference in the slopes of PL and DDAVP. The slope of weight loss versus time for PL + DDAVP was 0.007±0.002 kg/min (F = 14.980, $p<0.005$). Interestingly, 37% of the DDAVP trials (7 of 19) registered a weight loss less than 0.5 kg, but the dive times were all less than ~210 min.

The fractional weight loss for PM dives is presented in Figure 3 (lower). The average fractional loss was significantly less for DDAVP (1.2±0.3%) than for PL (1.9±0.2%, $p<0.05$). There was also a distinct correlation between fractional loss and dive time for both DDAVP and PL; the slope for DDAVP was not different than the PL

slope. The slope of the combined data shown in the figure indicates an average rate of fluid loss of 0.5±0.1% total body weight per hour of dive.

Weight Loss, All AM & PM Dives

Since there were no significant differences between AM and PM dives, the data were combined to estimate rates of change in loss of body weight. Figure 4 (top) illustrates a significant correlation between weight loss and dive time for the 94 AM and PM dives. The average weight loss was 1.30±0.09 kg, with a 95% confidence interval of 0.18 kg. Notice that the distribution for DDAVP trials falls within the PL data set.

Figure 4 (lower) presents the fractional weight loss for AM and PM dives. Based on the slope of the relationship, the rate of fluid loss is 0.4±0.1% total body weight per hour of dive.

Exercise Heart Rate, AM and PM Dives

Figure 5 (top) illustrates step test exercise heart rates for AM dives. There were no significant differences between PL and DDAVP. The magnitude of the post-dive increase in exercise heart rate was similar for PL (2.2±1.5 beats/min) and DDAVP (3.5±2.7 beats/min). Overall, the magnitude of the increase in post-dive heart rate averaged 2.7±1.4 beats/min for AM dives. There were no meaningful correlations between the increase in post-dive heart rate and dive time or weight loss.

Figure 5 (lower) presents exercise heart rate data for PM dives. A significant increase in post-dive heart rate occurred with PL trials; the magnitude of the increase

averaged 8.3±1.5 beats/min. The slight decrease in heart rate for DDAVP in the post-dive period was not significant.

Tympanic Temperature

Figure 6 (top) illustrates that post-dive tympanic membrane temperature was significantly lower than pre-dive values for both AM and PM dives. The pre-dive values for PM dives were significantly higher than AM dives. This difference largely accounted for the significantly greater post-dive decrease for PM dives (1.1±0.1 °C) than for AM dives (0.6±0.1 °C, $p<0.02$). Overall, the post-dive decrease in temperature was 0.9±0.1 °C for AM and PM dives. There were no significant differences in temperature between PL and DDAVP for the respective AM and PM dives.

The post-dive values averaged 35.5±0.2 °C for AM and PM dives. No subject reported any shivering or any sense of being cold. In fact, several divers mentioned that they felt warm during the dive. These low post-dive values do not reflect a true core temperature; likely, they were due to the effect of cool water in the ear canal lowering the tympanic membrane temperature independently of any change in core temperature.

Figure 6 (lower) indicates that the change in tympanic temperature (pre minus post-dive) was not significantly affected by dive time.

Diet Survey

Table 2 presents the averaged data for selected nutrients for the AM and PM periods. There were no appreciable differences between AM and PM data. However,

variations were noted within and between subjects that seemed to relate to work schedules and on-site cooking facilities. In general, subjects tended to either obtain meals from the Navy Exchange or a fast-food restaurant, or they prepared their own meals using the on-site microwave or charcoal grill. The restaurant-type meals often included submarine or cheeseburger sandwiches, while on-site meals frequently included grilled chicken, rice, or microwaved tacos. Total variety and balance were limited. Meal spacing was irregular, largely because of the dive work schedules. Eating patterns appeared more irregular when subjects were assigned non-diving duties like dive supervisor or stand-by diver.

Total caloric intake reported by the subjects was 3400-3500 kcal/day. Approximately 47% of the calories were obtained from carbohydrate and 35% from fat. Total carbohydrate intake was 409-434 gm/day. Cholesterol intake was close to the Recommended Daily Allowance (RDA, 300 mg/day).

Sodium intake exceeded the RDA range for males (1100-3300 mg/day) whereas potassium intake approximated the RDA range (1875-5625 mg/day). Calcium and iron intake were above the RDA (800 and 10 mg/day, respectively).

DISCUSSION

Loss of Body Fluid

The post-dive weight losses in the present study for AM and PM dives (1.30 kg) were consistent with values obtained previously (1.31 kg) during night SDV dives (3). The average weight loss in the present study represented 1.7% of total body weight.

Two-thirds of all dives had a weight loss equivalent to 0.5-2.0 liters of body fluid (0.5-2.0 qts).

The present study demonstrated that weight loss was similar between AM and PM dives, indicating an absence of a nocturnal effect on fluid loss. Laboratory studies have noted that nighttime immersions result in less diuresis (2, 5, 9), and therefore less fluid loss, than daytime immersions. This apparent difference between laboratory and open-water dives has been explained previously (3) by a shift in the divers' diurnal pattern of urine production. Laboratory studies usually involved a single nighttime exposure, whereas the divers in this study were operating continuously in daytime or nighttime routines. Thus, it is reasonable to expect that diurnal variations in urine production would adapt to continuous AM or PM work schedules. Furthermore, the magnitude of the weight loss for AM and PM dives approximated weight losses or urine volumes produced during AM laboratory immersions (1, 2, 5, 6, 8, 11). This suggests that data from daytime laboratory studies can be suitably extrapolated to anticipated fluid loss during AM or PM open-water dives.

In contrast to the previous open-water study (3), this investigation noted a positive correlation between weight loss and dive time for both AM and PM dives. One reason for this difference may be the larger n value in the present study. Although there was a large individual variation in weight loss, the correlation established a weight loss of 0.5% of body weight per hour of dive, or approximately 360 ml of fluid per hour.

No doubt the rate of change in body weight was influenced by the fact that the

data points were obtained from dives lasting at least 2 hours (excluding 2 dives lasting 85 min). Immersion presents a fixed stimulus (translocation of blood to the thorax) for diuresis. Diuresis reaches a peak in 30-90 minutes after the onset of immersion and declines thereafter in the absence of fluid intake (1, 6, 8, 10). It is reasonable to conclude that a large measure of the fluid available for excretion would have already been lost by 2 hours of immersion. Thereafter, a smaller fraction of the total fluid lost would be excreted; this, in essence, reduces the slope of loss versus time for a data set encompassing 2-6 hours. Including data points for times of 0-2 hours probably would have resulted in a non-linear weight loss versus dive time relationship. However, since most SDV dives would be expected to last at least 2 hours, linear regression is sufficient to estimate rates of fluid loss. In the present study the regression analysis (from Fig. 4) estimates weight loss from 0.80-2.00 kg for 2- to 6-hour dives. There is substantial individual variation in weight loss; using a mean loss of 1.30 kg (1.7% total body weight) provides a rapid estimate sufficient for any 2- to 6-hour dive.

Increasing the size of the data set might improve estimates of fluid loss. Figure 7 (top) illustrates weight loss versus dive time for 102 nighttime dives (66 from PM dives in this study and 36 PM dives from reference 3). Mean weight loss is 1.31 kg. The variation around the linear estimate is still large, with the regression analysis predicting weight loss of 0.86-1.82 kg for 2- to 6-hour dives.

Since the AM dives were not appreciably different from PM dives, these additional 28 values were added to the data set shown in Figure 7 (lower). About 65%

of the data encompass dives lasting 2-4 hours, or 68% representing 3- to 6-hour dives. The complete regression equation to predict weight loss for these 130 SDV dives is:

$$\text{WT LOSS} = [(0.004 \pm 0.001) * \text{TIME}] + (0.472 \pm 0.245)$$

where weight loss is in kg and time in minutes. The above equation predicts weight loss of 0.95-1.91 kg for 2-6 hour dives. The average weight loss is 1.29 kg, a value not appreciably different from other estimates presented in this report.

The above predictive equation is constrained by the following. First, it covers dive times of 2-6 hours. Shorter dive times are irrelevant to significant fluid loss. Longer times might slightly modify the prediction. Second, the equation does not include conditions of ingesting fluid during a dive or of volume loading (drinking a large amount of fluid) shortly before the dive; both can substantially modify predicted fluid loss. Third, the equation estimates fluid loss for SDV dives, where divers are not performing hard work. It is unknown whether it would be applicable to other exercising situations (i.e., combat swimmer). Fourth, the data were obtained in temperate water dives. Additional studies are needed to validate the prediction in hot water diving. Since negligible differences in fluid loss occur between thermoneutral and cold water immersions lasting more than 2 hours (1), the equation could be applied to cold water SDV operations.

Inhibition of Fluid Loss

The drug DDAVP has been shown to be very effective in reducing the diuresis

in normal persons receiving a water load (12, 13). It has also been reported by Lockette (personal communication) to reduce immersion diuresis by 80-90% at rest during 3 hours in thermoneutral water.

The present data were obtained using the same dose of DDAVP (20 μg ntranasally) employed by Lockette. There was enough variability in the response to DDAVP to preclude observing a striking effect of the drug, especially in the AM series where the sample size was small. Among all PM dives the use of DDAVP reduced weight loss by 37% (~0.6 kg) compared to PL trials. Using just the paired data of subjects, DDAVP reduced weight loss by only 44% (~0.6 kg). Under normal laboratory conditions 96% of the weight loss during immersion can be accounted for by urine production (10). If this applied to the present study conditions, and DDAVP reduced diuresis by 80%, one would have expected to see post-dive weight loss with use of the drug on the order of only 0.3 kg (or 1.2 kg less than PL dives).

Inspection of Figure 4 revealed that only 8 of 20 DDAVP trials had a weight loss <0.5 kg for dives lasting less than 3.5 hours, and 0 of 8 trials had a similar result in dives lasting longer than 3.5 hours. Several reasons may account for the smaller than expected effect of DDAVP in these open-water dives. The purpose of the present study was to determine the efficacy of DDAVP under operational situations, without the usual restrictive and controlled conditions employed in laboratory investigations. Pre-dive hydration status may have varied day-to-day among and within subjects. This would have subsequently affected the magnitude of fluid loss during a particular dive.

Support for such day-to-day variation is indicated by the 1.58 kg average difference between minimum and maximum weight changes for all PL dives.

It is also possible that the DDAVP dose (20 μg) may be somewhat low to produce a marked effect on hydration during open-water dives. Rado et al (7) found that 10- and 20-μg intranasal doses of DDAVP were about equipotent to inhibit water-loaded diuresis; a clear separation in the antidiuretic effect of the drug was more evident at higher doses (40-320 μg) Based on body weight, subjects in the current study received 0.21-0.32 μg DDAVP/kg body weight, but no obvious association was observed between the magnitude of weight loss and the per kg dose of the drug.

The duration of action of a single 20 μg DDAVP dose may not remain fully effective for dives lasting more than 3-4 hours. This same dose applied to fluid loaded volunteers reduced urine flow to ~1 ml/min within 1-2 hours (13). It was noted, though, that flow had slowly increased to ~1.5 ml/min by the 4th hour of observation; plasma concentrations of DDAVP did not change during this time. If the effectiveness of DDAVP decreased during longer dives, urine flow would concomitantly increase. Thus, post-dive weight loss with the drug might be comparable to PL trials, as was observed. Temporal measures of fluid loss were not possible in these subjects, but such an approach in the laboratory setting could address the issue of how long a single dose might be effective.

It is evident that additional studies are needed before it can be determined whether DDAVP would be of significant benefit to a SEAL under operational conditions. Based on this study it can be concluded that use of DDAVP is safe, but

produces only a modest and variable reduction in fluid loss during open-water SDV dives.

Exercise Heart Rate

Post-dive exercise heart rate was 8 beats/min higher than pre-dive values for PM dives, similar to the 12 beats/min found in previous night dives (3). The higher exercise heart rate was consistent with the modest dehydration, measured by weight loss. It is commonly accepted that heart rate would increase 10 beats/min for each 1.5% decrease in body weight. On this assumption, the 1.7% decrease in body weight should have increased heart rate by ~11 beats/min. This is close to the measured PM values.

Aside from the smaller number of observations, the lack of a significant effect on heart rate in the AM series may be explained by slightly different environmental conditions from the PM exercise testing. Air temperature was about 5 °C higher during the daytime testing, which may account for the higher pre-dive values for AM than PM (note Figure 5). Post-dive testing was accomplished shortly after subjects exited the water, and presumably before air temperature would appreciably alter body heat stores. Thus, changes in heart rate from pre-dive to post-dive may be more closely related to hydration status in the PM dives.

Use of DDAVP during PM dives did not result in a significant change in post-dive exercise heart rate. This finding is consonant with less of a decrease in body weight than during PL trials.

Tympanic Temperature

It was hoped that tympanic membrane temperature would provide a reliable index of body core temperature. While no independent measure of core temperature was obtained simultaneously with tympanic temperature, the pre-dive values of tympanic temperature appear to be a reasonable measure of core temperature.

Post-dive measures of tympanic temperature were too low to be reasonably accepted as an index of core temperature. A value of 35.5 °C would usually be interpreted as moderate hypothermia. It is extremely unlikely that the divers were hypothermic. First, the water temperature was 26 °C and the divers were wearing some thermal protection. Second, they were performing some level of work during the SDV dives. In fact, subjects that functioned as mission specialists and were swimming outside the SDV, often remarked of feeling too warm. Third, questioning of the divers revealed that they did not experience shivering nor did they perceive themselves as feeling cold.

The most probable explanation for the low post-dive tympanic temperatures is that water in the ear canal cooled the otic tissues, including the tympanic membrane. Submersion for an extended period affords the opportunity for water to enter the ear canal and cool the tissues. The ear canal was always swabbed with tissue before taking a measurement, so the otoscope was not scanning a water droplet. Operators were skilled in the use of otoscopes, ensuring that the tympanic membrane was scanned and not some other structure.

It can be concluded that measurement of tympanic membrane temperature will

not provide a reliable post-dive measure of core temperature. Significant underestimations of core temperature will occur.

Diet

Apart from the difficulties of conducting diet surveys in field settings, the results suggested that the overall nutritional intake was adequate. There were, however, several noteworthy observations.

The work schedule for AM and PM dives generally precluded evenly spaced meals and regular use of available dining facilities. Most commonly, SEALs ate several meals per day, usually when there was a break in their schedule. To their credit, they managed to maintain an adequate intake under these circumstances. Interestingly, the dive supervisor and stand-by diver had the least opportunity to eat during dive operations because they were on the support vessel throughout the entire AM or PM session.

Meal planning was limited. Generally, the divers either prepared food at the dive site from ingredients purchased at a grocery store, or they bought sandwiches, pizza, or fast-food from commercial establishments. There seemed to be a general awareness of the need for good nutrition. Detailed knowledge of nutritional requirements was lacking, but probably on a par with the general public.

On-site facilities for cooking were spartan. One microwave and a grill were used by the entire platoon to individually prepare food. Two operational refrigerators were available. Most often, individuals prepared their food rather than a collective meal for a group.

The above observations likely accounted for the large variability in the 3-day diet surveys. Thus, the average of the 3 days is probably accurate but does not reflect the variability. In addition, the diversity of dietary patterns between the divers prevents making a general conclusion about what the "average" SEAL eats in this type setting.

LAY LANGUAGE SUMMARY

Weight loss after 28 daytime (AM) and 66 nighttime (PM) dives were obtained in 13 SEALs conducting Advanced Operator Training in a SEAL Delivery Vehicle (SDV). Water temperature was 26 °C (79 °F). Dives lasted 85-385 minutes; average depth was 20 fsw. Divers wore light thermal protection and used the MK-15 closed-circuit underwater breathing apparatus. No diver experienced shivering or the sense of being cold.

AM dives lasted 166±8 minutes, with an average weight loss of 1.25±0.14 kg (2.5±0.3 lbs). The weight loss translates to an average loss of body fluid of 1.2 liters (1.3 quarts). PM dives lasted 234±7 minutes with a weight loss of 1.35±0.12 kg (2.9±0.3 lbs); this weight loss equated to loss of 1.3 liters (1.4 qts) and was comparable to the AM loss. For all dives the predicted weight loss would be 0.8-2.0 kg (0.8-2.0 quarts of body fluid) for 2-6 hour SDV dives.

DDAVP is a drug that is an analog of the naturally occurring hormone vasopressin, which reduces the amount of urine produced during immersion. During 9 AM and 19 PM man-dives, 20 micrograms of DDAVP in nose drop form were given one hour before the start of the dives to determine if the drug would significantly reduce fluid loss. No significant change in weight loss with DDAVP occurred during the AM dives, but the drug lessened weight loss in PM dives by 0.6 kg (1.3 lbs).

Weight loss from all AM and PM dives was combined with similar PM data obtained in 1991 to provide a reasonable equation to predict how much fluid would be lost during a dive. The predictive equation is:

$$\text{FLUID LOSS (qts)} = 0.004 \ * \text{DIVE TIME (minutes)} + 0.47$$

This equation can be used for any SDV dive to estimate fluid loss and determine how much fluid needs to be consumed after the dive to restore hydration status. For example, 1.2 quarts of fluid would be lost during a 3-hour dive (180 minutes). Drinking this amount of fluid after the dive would reverse the dehydration resulting from the dive.

This study also noted that dietary intake of calories was approximately 3500 kilocalories per day; 47% of the calories were obtained from carbohydrate and 35% from fat. Large individual variations were observed that were related to factors such as spartan on-site cooking facilities and work schedules that precluded regular use of messing facilities.

CONCLUSIONS/RECOMMENDATIONS

1. Average body fluid loss for 2- to 6-hour SDV dives will be 1.4 quarts regardless of whether the dive is conducted in the daytime or nighttime. Drinking this amount of fluid after a dive will restore hydration status.

2. Estimated fluid loss during an SDV dive is 0.25 quarts per hour of dive time plus 0.50 quarts.

3. The drug DDAVP lessened loss of body fluid during SDV dives by 0.6 quarts, but considerable individual differences existed. It is unknown whether this effect would improve SEAL performance during long missions.

4. Use of DDAVP cannot be recommended at this time. Further testing is needed to determine how effective it will be.

5. SEALs have adequate nutritional intake during field deployment for warm weather AOT training. Improvements in on-site meal planning and preparation could substantially improve divers' diets. At present, there is no "typical" SEAL diet under these field conditions.

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ANNEX A
INDIVIDUAL SUBJECT DATA

SUBJECT NUMBER	AM=0 PM=1	PL=0 DAVP=1	DIVE TIME (min)	WEIGHT LOSS (kg)	CHANGE HEART RATE (bpm, 99=no data)
6.,	1.,	0.,	185.,	1.36,	4.,
7.,	1.,	0.,	185.,	1.55,	6.,
2.,	1.,	0.,	170.,	0.68,	20.,
8.,	1.,	0.,	170.,	0.90,	8.,
4.,	1.,	0.,	195.,	1.81,	-8.,
5.,	1.,	0.,	195.,	1.36,	8.,
3.,	1.,	0.,	210.,	1.13,	4.,
11.,	1.,	0.,	210.,	1.58,	12.,
12.,	1.,	0.,	235.,	1.13,	12.,
9.,	1.,	0.,	235.,	0.23,	16.,
1.,	1.,	0.,	195.,	0.91,	16.,
10.,	1.,	0.,	195.,	0.11,	4.,
2.,	0.,	0.,	195.,	1.81,	4.,
9.,	0.,	1.,	195.,	0.32,	4.,
7.,	0.,	0.,	205.,	2.50,	8.,
3.,	0.,	1.,	205.,	0.91,	20.,
6.,	0.,	0.,	115.,	0.68,	4.,
8.,	0.,	1.,	115.,	1.36,	-4.,
13.,	0.,	0.,	245.,	0.91,	-16.,
11.,	0.,	1.,	245.,	1.13,	4.,
10.,	0.,	0.,	155.,	0.34,	-8.,
4.,	0.,	1.,	155.,	0.91,	-4.,
5.,	0.,	0.,	180.,	1.81,	0.,
1.,	0.,	1.,	180.,	0.68,	0.,
8.,	0.,	0.,	170.,	2.05,	8.,
7.,	0.,	1.,	170.,	2.72,	4.,
3.,	0.,	0.,	175.,	2.04,	4.,
2.,	0.,	1.,	175.,	2.72,	4.,
11.,	0.,	0.,	190.,	0.91,	-8.,
10.,	0.,	0.,	190.,	0.68,	2.,
1.,	0.,	0.,	175.,	2.05,	4.,
12.,	0.,	1.,	175.,	1.25,	-20.,
4.,	0.,	0.,	180.,	1.13,	4.,
9.,	0.,	0.,	180.,	1.36,	4.,
8.,	0.,	0.,	125.,	1.36,	99.,
9.,	0.,	0.,	125.,	0.91,	99.,
6.,	0.,	0.,	85.,	0.00,	99.,
2.,	0.,	0.,	85.,	0.91,	99.,
3.,	0.,	0.,	125.,	0.68,	99.,
7.,	0.,	0.,	125.,	0.45,	99.,
8.,	1.,	0.,	190.,	0.80,	12.,
3.,	1.,	1.,	190.,	1.13,	4.,
4.,	1.,	1.,	180.,	1.25,	0.,
1.,	1.,	0.,	180.,	0.45,	4.,

ANNEX A (continued)

SUBJECT	AM/PM	PL/DAVP	TIME	WT. LOSS	CHANGE HR
10.,	1.,	1.,	205.,	0.45,	-16.,
2.,	1.,	0.,	205.,	1.36,	4.,
7.,	1.,	1.,	205.,	1.36,	0.,
13.,	1.,	0.,	205.,	0.68,	4.,
8.,	1.,	0.,	150.,	2.50,	4.,
9.,	1.,	1.,	150.,	0.91,	0.,
6.,	1.,	0.,	210.,	0.91,	22.,
5.,	1.,	1.,	210.,	0.90,	-24.,
10.,	1.,	0.,	270.,	0.68,	8.,
3.,	1.,	0.,	270.,	2.50,	8.,
2.,	1.,	1.,	190.,	0.45,	0.,
1.,	1.,	1.,	190.,	0.23,	0.,
11.,	1.,	1.,	200.,	0.34,	-18.,
6.,	1.,	1.,	135.,	0.00,	4.,
11.,	1.,	0.,	135.,	0.91,	12.,
9.,	1.,	0.,	120.,	0.68,	8.,
12.,	1.,	1.,	120.,	0.00,	0.,
5.,	1.,	0.,	140.,	2.04,	20.,
7.,	1.,	0.,	140.,	2.72,	4.,
8.,	1.,	1.,	260.,	1.58,	99.,
4.,	1.,	0.,	260.,	0.46,	99.,
11.,	1.,	0.,	270.,	1.36,	99.,
1.,	1.,	0.,	270.,	1.14,	99.,
9.,	1.,	0.,	375.,	2.38,	99.,
7.,	1.,	0.,	375.,	4.09,	99.,
2.,	1.,	0.,	285.,	1.70,	99.,
5.,	1.,	0.,	285.,	2.95,	99.,
12.,	1.,	0.,	315.,	1.81,	99.,
3.,	1.,	0.,	315.,	2.50,	99.,
10.,	1.,	0.,	250.,	2.04,	99.,
13.,	1.,	0.,	250.,	2.05,	99.,
1.,	1.,	0.,	285.,	1.59,	99.,
11.,	1.,	1.,	285.,	0.68,	99.,
10.,	1.,	0.,	270.,	0.84,	99.,
4.,	1.,	1.,	270.,	2.15,	99.,
2.,	1.,	0.,	300.,	1.36,	99.,
5.,	1.,	1.,	300.,	1.59,	99.,
9.,	1.,	0.,	300.,	0.57,	99.,
7.,	1.,	0.,	300.,	5.44,	99.,
13.,	1.,	0.,	300.,	0.91,	99.,
3.,	1.,	1.,	300.,	0.91,	99.,
7.,	1.,	0.,	300.,	1.36,	99.,
9.,	1.,	1.,	300.,	0.68,	99.,
4.,	1.,	0.,	300.,	1.93,	99.,
8.,	1.,	1.,	300.,	2.40,	99.,
10.,	1.,	0.,	240.,	0.79,	99.,
6.,	1.,	1.,	220.,	0.11,	99.,
6.,	1.,	0.,	255.,	1.48,	99.,
8.,	1.,	0.,	255.,	1.13,	99.,
3.,	1.,	0.,	280.,	1.59,	99.,

TABLE 1

PHYSICAL CHARACTERISTIC OF INDIVIDUAL SUBJECTS
(mean ±SD for n = 13 at bottom of table)

SUBJECT #	AGE (yr)	HEIGHT (cm)	WEIGHT (kg)	MEAN SKINFOLD (mm)	% BODY FAT
1	21	173	73.48	9.9	9.5
2	21	175	70.31	9.1	8.8
3	20	175	72.57	9.4	9.0
4	20	173	68.04	10.4	10.0
5	24	185	94.12	12.6	12.5
6	28	173	64.18	6.4	6.7
7	23	185	83.91	5.7	5.5
8	25	175	72.57	5.8	5.8
9	30	173	83.91	16.2	16.5
10	33	175	83.91	14.6	15.4
11	22	183	83.01	15.4	14.8
12	24	182	71.67	7.5	7.5
13	30	174	63.50	5.2	5.8
MEAN	**24.7**	**177**	**75.78**	**9.9**	**9.8**
S.D.	**4.2**	**5**	**9.15**	**3.8**	**3.8**

TABLE 2

DIETARY INFORMATION
FROM 3 DAY DIET SURVEYS
(mean ± SEM)

	AM DIVES (n = 9)	PM DIVES (n = 8)
BODY WEIGHT (kg)	75.90 ± 3.16	76.66 ± 3.94
CALORIC INTAKE (kcal/kg/day)	46.81 ± 3.44	43.52 ± 4.65
CARBOHYDRATE (gm/kg/day)	5.72 ± 0.50	5.33 ± 0.71
PROTEIN (gm/kg/day)	1.91 ± 0.20	1.70 ± 0.22
TOTAL FAT (gm/kg/day)	1.72 ± 0.20	1.61 ± 0.17
SATURATED FAT (gm/kg/day)	0.46 ± 0.05	0.53 ± 0.06
CHOLESTEROL (mg/kg/day)	4.09 ± 0.59	4.80 ± 0.70
SODIUM (mg/kg/day)	74.36 ± 7.19	67.09 ± 8.85
POTASSIUM (mg/kg/day)	49.42 ± 4.82	53.66 ± 7.76
CALCIUM (mg/kg/day)	16.54 ± 1.80	18.93 ± 2.86
IRON (mg/kg/day)	0.30 ± 0.02	0.34 ± 0.04

FIGURE LEGENDS

FIGURE 1. **TOP:** Number of dives for all AM and PM dives according to range of dive times. >60 = 85-119, >120 = 120-179, >180 = 180-239, >240 = 240-299, >300 = 300-359, and >360 minutes.

LOWER: Number of dives for all AM and PM dives according to the range of post-dive body weight loss. <0.5 = 0-0.49, <1 = 0.51-1.00, <2 = 1.01-2.00, <3 = 2.01-3.00, <4 = 3.01-4.00, and >4.00 kilograms (kg).

FIGURE 2. **TOP:** Weight loss versus duration of AM dives for placebo (PL) and DDAVP. Each symbols represents one man-dive. Regression equation developed from PL + DDAVP data sets.

LOWER: Fractional weight loss [(pre-post)/pre] for AM dives.

FIGURE 3. **TOP:** Weight loss versus duration of PM dives for PL and DDAVP. Each symbols represents one man-dive. Regression equation developed from PL + DDAVP data sets.

LOWER: Fractional weight loss for PM dives.

FIGURE 4. **TOP:** Weight loss for all 94 AM and PM SDV dives. Filled symbol denotes DDAVP trials; 8 of 28 had weight loss <0.5 kg. Average weight loss for all dives was 1.30 kg with a 95% confidence interval of 0.18 kg.

LOWER: Fractional weight loss for all AM and PM dives. Twelve of 28 DDAVP trials had a loss equal to <1% of total body weight.

FIGURE 5 **TOP:** Pre-dive and post-dive exercise heart rates for PL and DDAVP AM dives. No significant differences were found between or among conditions.

LOWER: Pre-dive and post dive exercise heart rates for PL and DDAVP PM dives. * represents significant difference from corresponding pre-dive value.

FIGURE 6. **TOP:** Tympanic membrane temperature recorded pre and post-dive for AM and PM dives. * represents significant difference from pre-dive values. # represents significant difference from pre-dive AM value.

LOWER: Change in tympanic membrane temperature (pre-dive minus post-dive) versus time of AM and PM dives. Each symbol represents one man-dive. Regression equation developed from AM + PM data sets; no significant change occurred as a function of dive time.

FIGURE 7. **TOP:** Post-dive weight loss versus dive time for all PM dives from this study plus the previous PM study (reference #3). Each symbol represents one man-dive. Average weight loss is 1.31 kg with a 95% confidence interval of 0.17 kg.

LOWER: Weight loss versus dive time for all PM dives included above, plus all AM dives from present study. Each symbol represents one man-dive. Average loss is 1.30 kg with a 95% confidence interval of 0.14 kg.

FIGURE 1

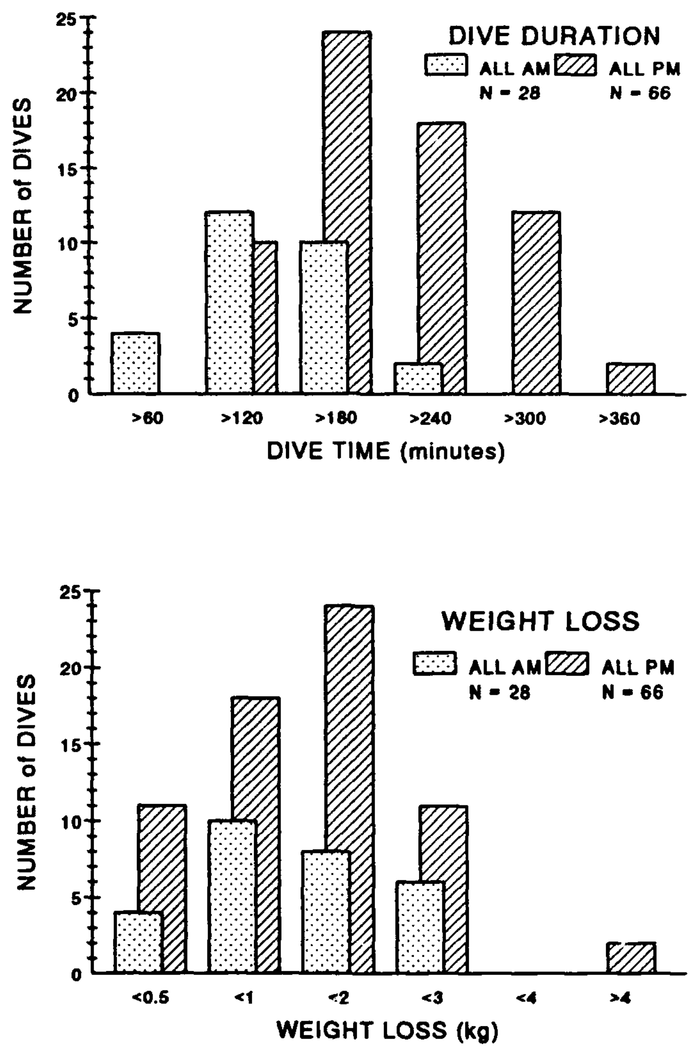
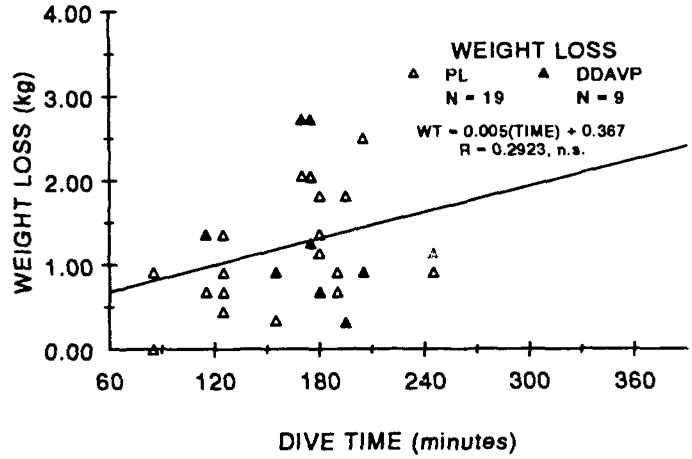

DIVE DURATION
ALL AM
N = 28
ALL PM
N = 66
NUMBER of DIVES
0
5
10
15
20
25
>60
>120
>180
>240
>300
>360
DIVE TIME (minutes)
WEIGHT LOSS
ALL AM
N = 28
ALL PM
N = 66
NUMBER of DIVES
0
5
10
15
20
25
<0.5
<1
<2
<3
<4
>4
WEIGHT LOSS (kg)

FIGURE 2
AM DIVES



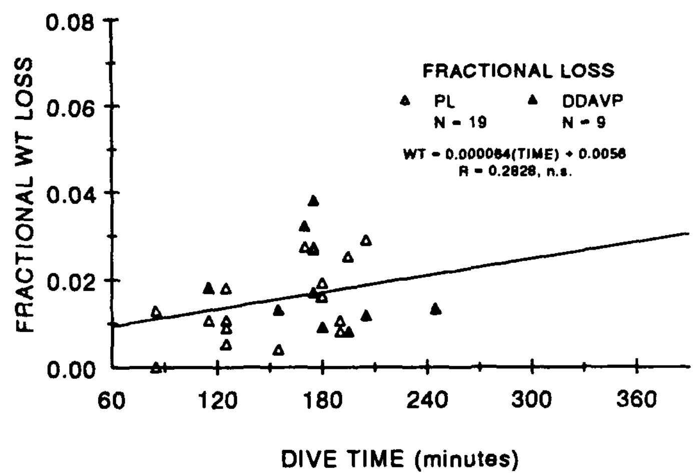


FIGURE 3
PM DIVES

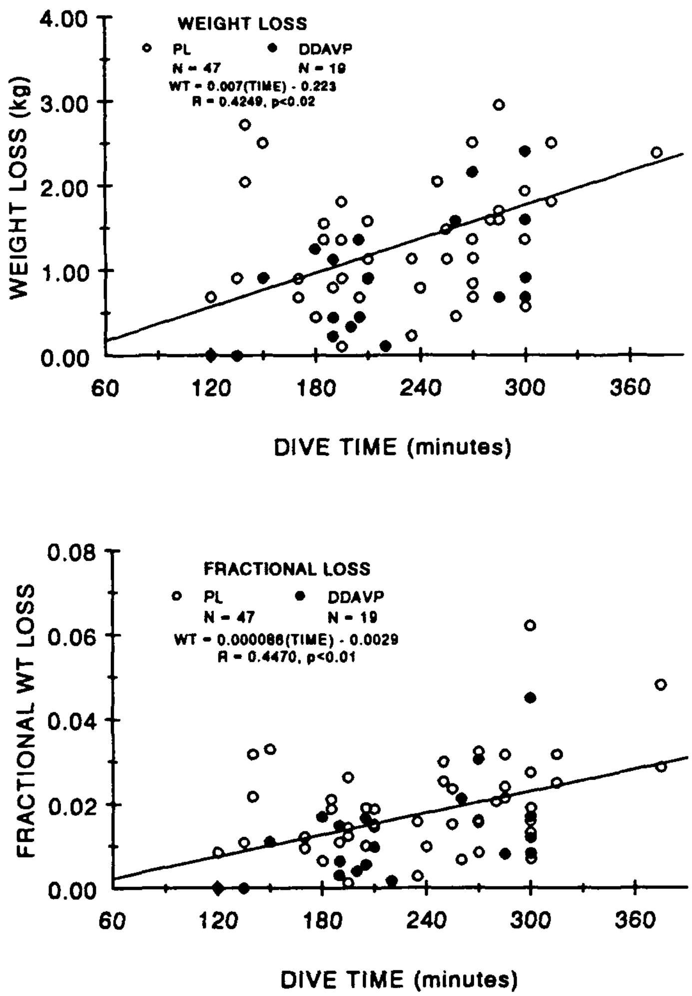
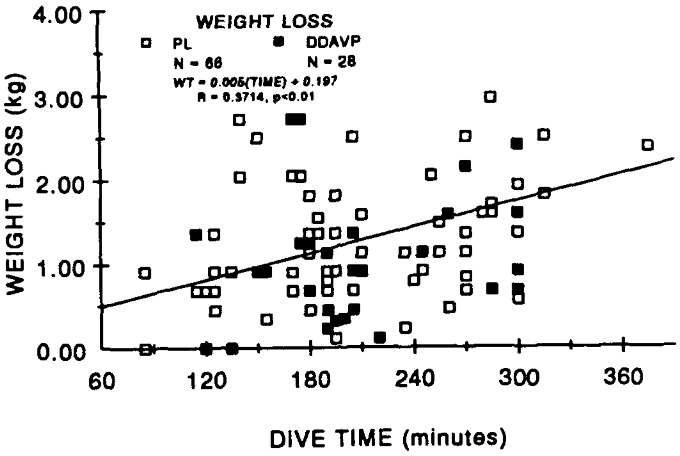


FIGURE 4
AM + PM DIVES



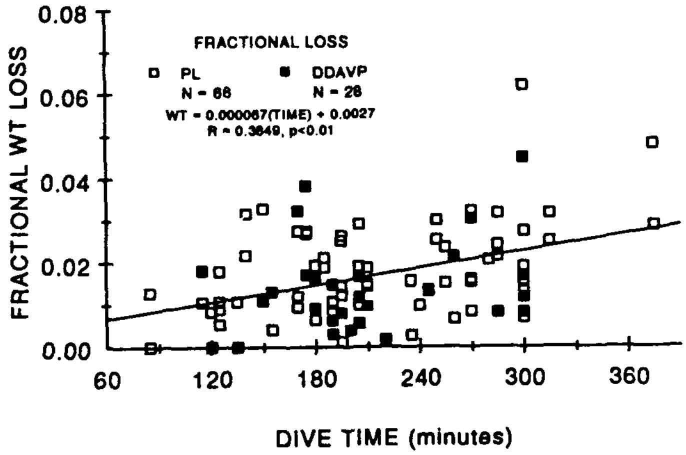


FIGURE 5

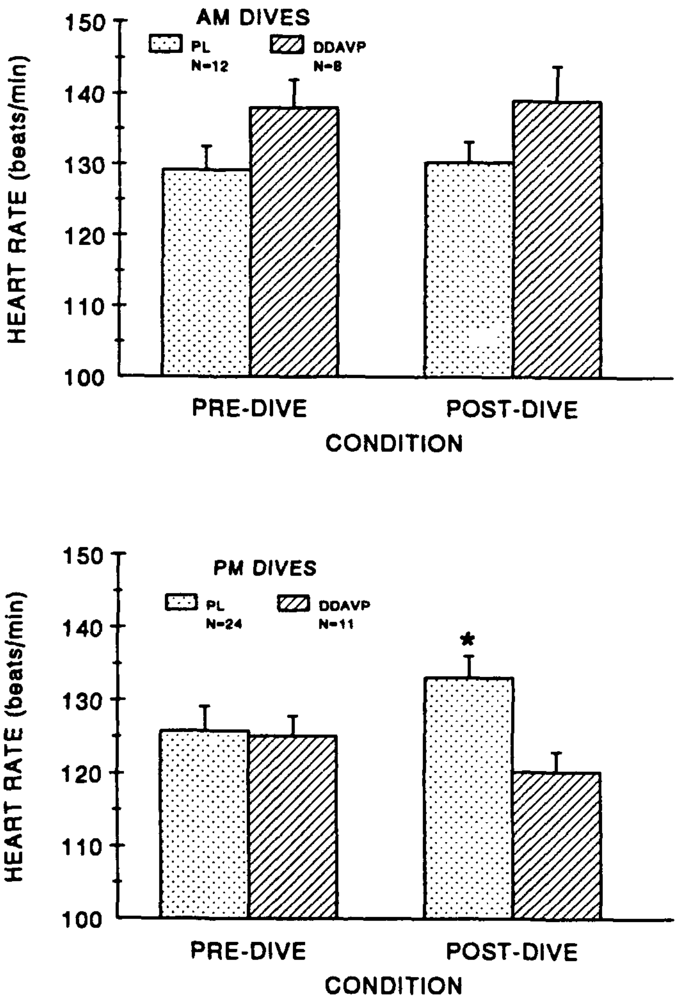
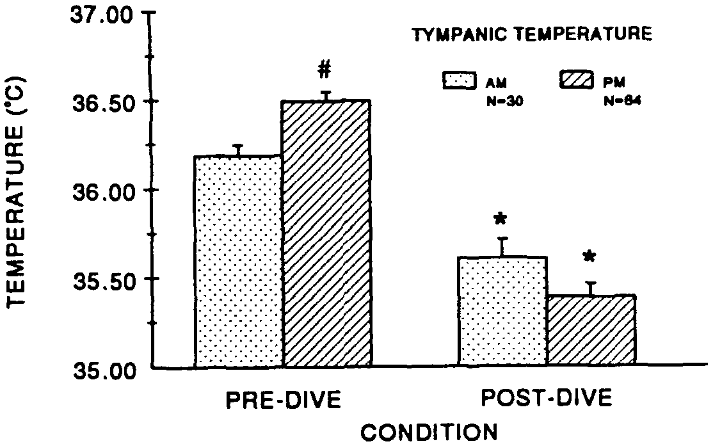
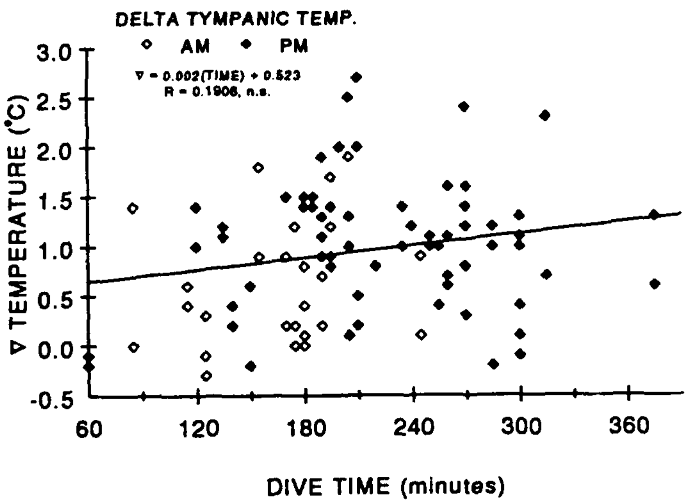

AM DIVES
PL N=12
DDAVP N=8
150
140
130
120
110
100
HEART RATE (beats/min)
PRE-DIVE
POST-DIVE
CONDITION
PM DIVES
PL N=24
DDAVP N=11
*
150
140
130
120
110
100
HEART RATE (beats/min)
PRE-DIVE
POST-DIVE
CONDITION

FIGURE 6

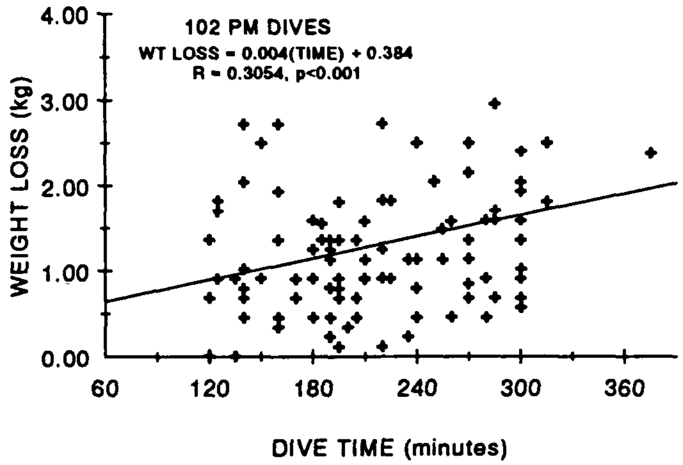


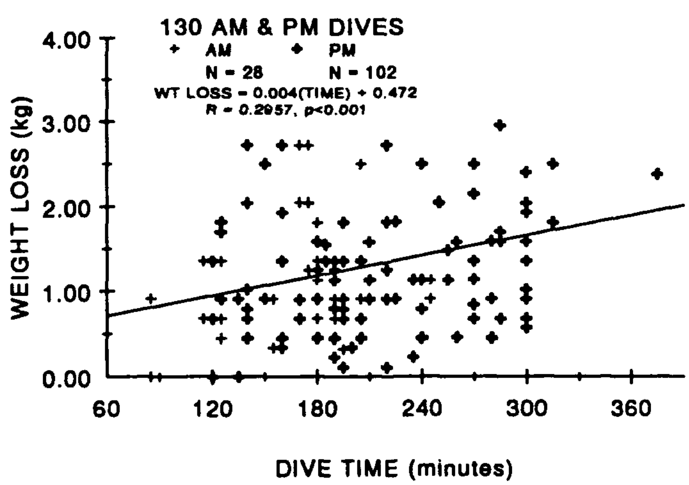
TYMPANIC TEMPERATURE
AM N=30
PM N=64
TEMPERATURE (°C)
37.00
36.50
36.00
35.50
35.00
#
*
*
PRE-DIVE
POST-DIVE
CONDITION



DELTA TYMPANIC TEMP.
AM
PM
∇ = 0.002(TIME) + 0.523
R = 0.1906, n.s.
∇ TEMPERATURE (°C)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
60
120
180
240
300
360
DIVE TIME (minutes)

FIGURE 7


102 PM DIVES
WT LOSS = 0.004(TIME) + 0.384
R = 0.3054, p<0.001
WEIGHT LOSS (kg)
4.00
3.00
2.00
1.00
0.00
60
120
180
240
300
360
DIVE TIME (minutes)


130 AM & PM DIVES
+ AM
✦ PM
N = 28
N = 102
WT LOSS = 0.004(TIME) + 0.472
R = 0.2957, p<0.001
WEIGHT LOSS (kg)
4.00
3.00
2.00
1.00
0.00
60
120
180
240
300
360
DIVE TIME (minutes)